U.S.-CHINA Clean Energy Research Center on Building Energy Efficiency (CERC-BEE)

CERC-BEE 1.0 FINAL SUMMARY REPORT
2011-2015

Advanced Lighting Controls in New and Existing Buildings

Lawrence Berkeley National Laboratory:
Peter M. Schwartz, Erik Page, Jordan Shackelford

Lutron Electronics Co., Inc.:
Dr. Robert Nachtrieb, Lead Scientist

China Academy of Building Research, Institute of Building Environment and Energy:
Dr. Wu Jianlin

Lutron Electronics:
Joan Wei

Prepared by
Lawrence Berkeley National Laboratory:
Peter M. Schwartz

1. Abstract

Since their introduction decades ago, lighting controls have presented a dilemma with regards to energy savings. These systems offer the potential for substantial energy savings, but it is extremely difficult to quantify exactly how much savings a particular lighting controls technology or strategy may yield. Even after a lighting controls system is installed, it can still be difficult to quantify savings as it can be extremely dependent on occupancy patterns, user preferences, seasonal variations, and/or weather patterns, which themselves can be extremely variable. The net result is that investments in energy efficiency lighting are often directed to more predictable – but perhaps less cost effective – technologies, such as higher efficacy light sources or lamps and ballast retrofits. Essentially decision makers often take the guaranteed and verifiable 20% savings over the potentially more difficult to verify 30%-50% savings.

This project gets at the heart of the matter relative to promoting advanced lighting control systems' adoption in the marketplace.

- First, is trusting that the estimated savings are achievable and accurately reported through the lighting control system.
- Second, how to more effectively commission these systems when we lack explicit information regarding their operation by separate control strategy and similarly, how can utility EE programs properly attribute savings to the various control strategies as required by their regulators for M&V purposes?
- Third, building a strong foundation to moving towards 'outcome-based' energy codes whereby compliance is accurately self-reported by the lighting control systems and we can eliminate the need for expensive and intrusive external EM&V.

2. Statement of Objectives

The main research objective was to determine how accurately lighting control systems self-report energy usage and savings once a given lighting control system is installed and commissioned with respect to the lighting loads it manages. To meet this objective, the research team developed a test protocol to evaluate measured versus reported lighting energy use over a variety of settings and environmental conditions. This test protocol was initially used to evaluate the Lutron Quantum system operation, and it can be further refined to evaluate other lighting controls systems more generally.

A secondary research objective was to evaluate how changes in energy savings corresponded to changes in lighting quality metrics. Specifically, the research team looked at which controls setting and environmental conditions generated energy savings and improved glare metrics and which conditions generated savings at the expense of lighting quality. This second research objective was added during testing, as we were able to extend and expand our testing period beyond what we had planned.

Other research objectives include identifying the energy savings associated with individual lighting system control strategies and to convincingly demonstrate lighting controls systems' added value and cost-effectiveness for effecting deep reductions in lighting energy and demand in existing US buildings and new construction in China.

3. Benefits to the Funding DOE office's Mission

Increasingly sophisticated and "connected" lighting controls systems are starting to address this dilemma. A new generation of lighting controls is emerging that can estimate energy use and savings down to the individual luminaire level and estimate how much energy the system is saving from each control strategy (e.g., daylight harvesting, occupancy sensing, etc.). This access to informative data has been missing until recently and may have value in a variety of ways:

- Building managers can see exactly how much energy their systems are using and explore strategies for achieving deeper savings.

- Lighting controls manufacturers can better market their systems by showing potential customers verified savings reports for applications from similar customers.
- Energy-efficiency program designers may be more interested in promoting advanced lighting controls systems investments when the risks associated with variable and/or unverified savings are mitigated.
- Regulators with an interest in reducing overall building energy use (rather than simply reducing lighting power density) can use this data for compliance verification for next generation "outcome-based" codes.

4. Greatest accomplishment(s) (1 paragraph)

For the first time, this project directly addressed this issue that there are no existing standards or test procedures that describe how lighting controls systems should measure, estimate, record or report energy use or attribute energy savings. It accomplished this by measuring lighting system performance over a broad range of conditions and controls settings, and then comparing reported luminaire-level energy use to measured energy use. While the test presents the reported-versus-measured results for a specific lighting controls system, the methodologies developed can be applied more broadly to lighting controls systems generally. Ultimately these methods may lead to test procedures and codes for lighting controls systems that ensure accurate and uniform energy use reporting.

5. Technical Discussion of Work Performed by All Parties

U.S. Budget
- 2014 budget was $115,000.
- 2015 budget was $100,000.
- FY14 Carryover into FY15; $63,523.

U.S. Industry Cost-share
- Contribution-To-Date: $260,000
- Projected Total: $445,000

Brief Description: Lutron Electronics Co., Inc. has provided significant cost-share both in terms of hardware/software (complete latest generation Quantum lighting controls system, sensor package, Finelite LED & fluorescent fixtures), and with on-site and remote technical support. Continuing engagement by Lutron's Lead Scientist, Dr. Nachtrieb, provided overall guidance and coordination with Lutron's resources in U.S. and China, and was an extremely valuable resource to the research team.

Revised Work Plan – 2015 Task Statements

Figure 1: Diagram (above) & photo of DOE's FLEXLAB facility at LBNL. This experiment utilized one of the two rotational test cells in this photo's foreground.

Task: Technology Evaluation (FLEXLAB):

- Finalized lighting controls systems' specification we evaluated.
- Developed experimental plan appropriate to evaluating the specified lighting controls system performance in the FLEXLAB testing facility.
- Installed lighting controls system in the FLEXLAB testing facility.
- Tested and evaluated lighting controls systems in FLEXLAB according to the experimental plan.

    - In each scenario tested, we compared FLEXLAB measured energy use, savings, etc., to that reported by Lutron system.
    - Identified scenarios that generated discrepancies in reported results.
    - We looked to establish corrections for Lutron system, and if not possible, we identified scenarios where Lutron system results were likely to have higher uncertainty levels.

- Prepared report detailing laboratory lighting controls system testing results (sample plots shown below).
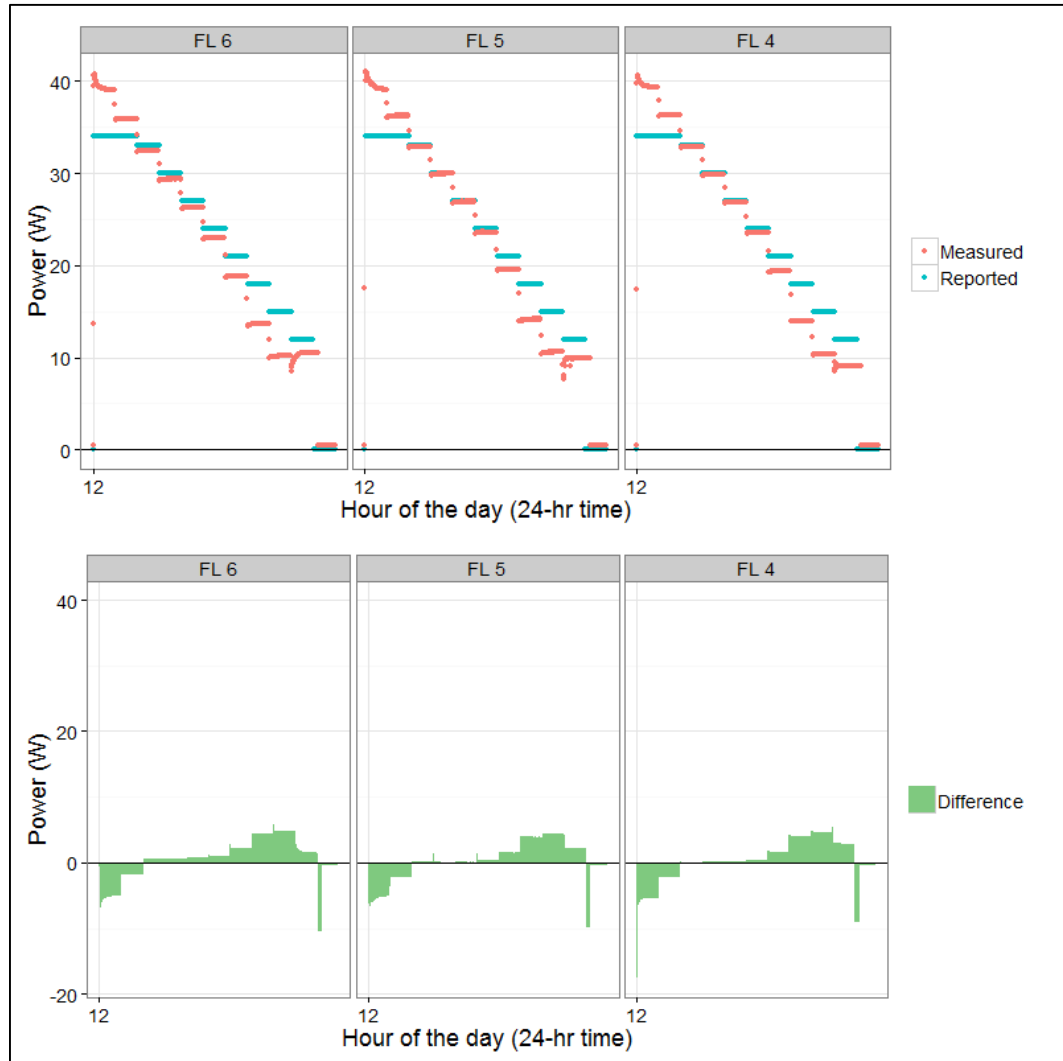
- Figure 2: Upper plot shows measured & reported power values, lower plot shows difference between reported & measured power for fluorescent luminaires during sample step dimming period
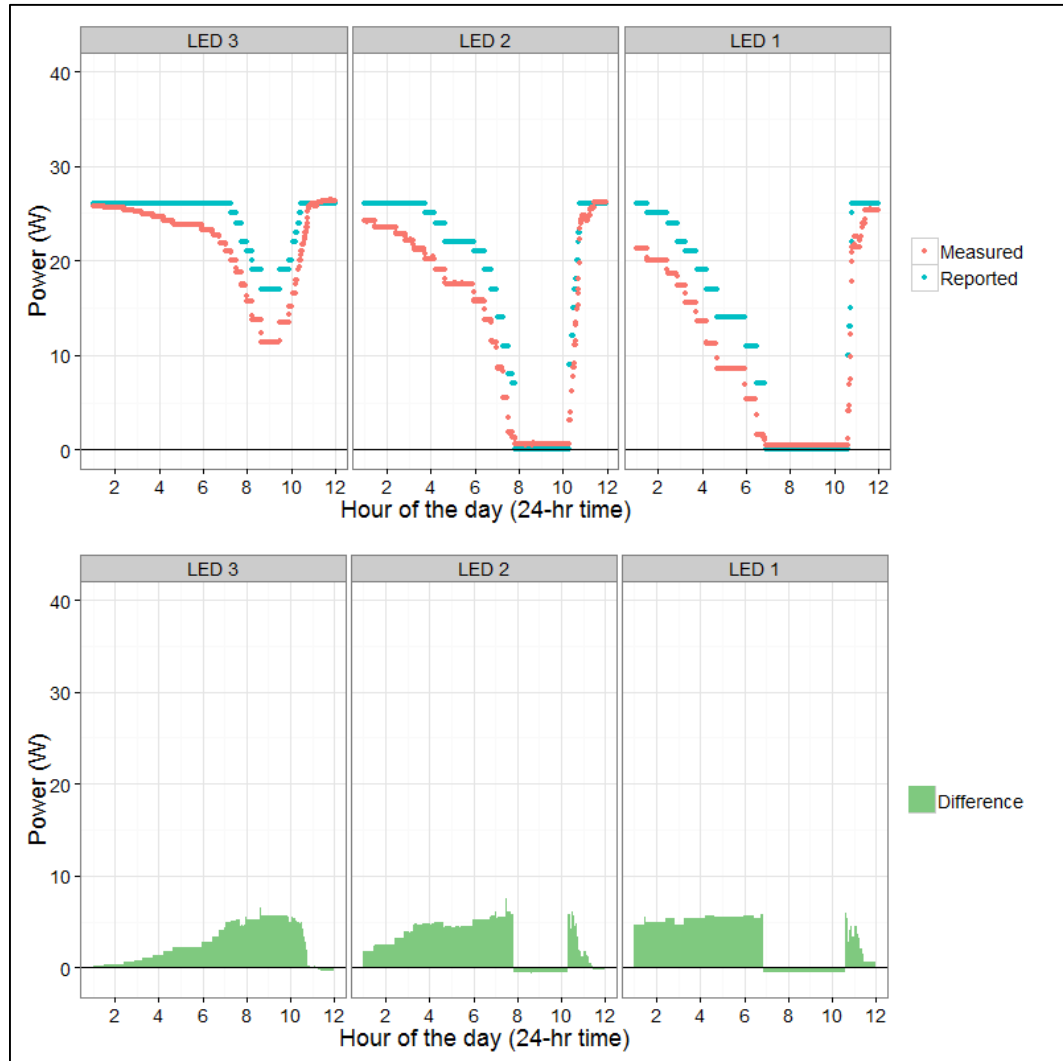
Figure 3: Upper plot shows measured & reported power values, lower plot shows difference between reported & measured power for LED luminaires during sample daylight harvesting period

- **Table 1: Average power as reported by FLEXLAB, under all control strategies for all luminaires**

Luminaire	Baseline (W)	Daylight Harvesting (W)	Savings	Occupancy Only (W)	Savings	Occupancy plus Daylight Harvesting (W)	Savings
FL 6	39.1	33.6	14%	20.2	48%	18.6	52%
FL 5	37.7	23.5	38%	20.3	46%	9.4	75%
FL 4	38.4	17.9	53%	20.4	47%	6.3	84%
All FL	**115.2**	**74.9**	**35%**	**60.8**	**47%**	**34.3**	**70%**
LED 3	26.5	21.9	17%	13.8	48%	12.0	55%
LED 2	26.4	15.6	41%	14.0	47%	5.9	78%
LED 1	25.7	11.1	57%	13.8	46%	4.0	84%
ALL LED	**78.7**	**48.7**	**38%**	**41.6**	**47%**	**21.9**	**72%**

- **Table 2: Average power as reported by Lutron system, under all control strategies for all luminaires**

Luminaire	Baseline (W)	Daylight Harvesting (W)	Savings	Occupancy Only (W)	Savings	Occupancy plus Daylight Harvesting (W)	Savings
FL 6	34	32.6	4%	17.3	49%	18.0	47%
FL 5	34	24.4	28%	17.2	49%	8.9	74%
FL 4	34	20.5	40%	17.2	49%	6.0	82%
All FL	**102**	**77.5**	**24%**	**51.7**	**49%**	**32.9**	**68%**
LED 3	26	24.9	4%	13.2	49%	13.8	47%
LED 2	26	19.4	25%	13.2	49%	6.8	74%
LED 1	26	15.5	40%	13.2	49%	4.6	82%
ALL LED	**78**	**59.8**	**23%**	**39.6**	**49%**	**25.2**	**68%**

Milestones:

- Installation of lighting controls systems in FLEXLAB   February 2015

Deliverables:

- Experimental plan for evaluating lighting controls system in FLEXLAB   January 2015
- Report with results and recommendations from FLEXLAB evaluation   April 2015

Task: Develop controls system reporting algorithms

- Vetted algorithms with industry stakeholders
- Revised algorithms to reflect appropriate feedback
- Provided technology transfer to industry stakeholders

Deliverables:

- Advanced lighting controls system reporting algorithm - Draft   October 2015
- Advanced lighting controls system reporting algorithm - Final   December 2015

Task: Develop proposed advanced lighting controls system standard for reporting

- Identify and contact key stakeholders in China working with CABR
- Identify and contact key U.S. stakeholders
- Establish advanced lighting controls system standard reporting template for dissemination
    - Vet template with U.S. code stakeholders
    - Distribute template to appropriate standards organizations

Deliverables:

- Advanced lighting controls system standard reporting template - Draft   September 2015
- Advanced lighting controls system standard reporting template – Final   January 2016

Task: Reporting

Deliverables:

- Quarterly progress reports – quarterly
- Annual project reports – annually
- Annual funding proposals – annually

6. **Major Outcomes & Achievements** *(include details such as name, description, date, patent#, etc.) – These will be used as talking points by Bob Marlay and Roland Risser when they brief Congress and Secretary Moniz, this is your opportunity to brag!*

We measured and confirmed, Lutron controls system's "notional power metering" for a variety of daylight and occupancy conditions. [**NOTE: All lighting control systems estimate energy consumption at either the aggregated node or device level through the use of standard lookup tables. This approach inherently limits reporting accuracy in particular with dynamic controls.**] This approach relates directly to two project objectives:

1. **Calibration/Verification of Notional Power Metering**: Comparing CABR field site reports generated by the Lutron controls systems to detailed measurements taken within the FLEXLAB will allow us to calibrate and correct (as needed) the reports generated by the Lutron controls systems. This will provide us with an improved understanding of the lighting system performance and energy use when viewing Lutron controls system reports.

2. Establishing **General Protocols for Notional Power Metering**: More generally, we explored and documented the opportunities and limitations of notional power metering and provided recommendations for **OPEN** industry standard approaches to utilizing these techniques in order to improve lighting controls system energy reporting accuracy.

Outcomes

For the first time, we **produced disaggregated energy savings at the device level with discrete attribution by control strategy** (i.e., the savings associated separately with occupancy sensing, daylighting, etc.).

All research products aimed at producing **open** and widely promulgated information, **NOT** information proprietary to Lutron.

- Leveraged research results with PG&E and NEEP which is working with us to calibrate their advanced lighting controls calculator using our actual FLEXLAB data to ensure its accuracy before rolling out to support their advanced lighting programs.

- The project directly builds the foundation to move to 'outcome-based' energy codes and standards and answers the utilities' desire to know how to attribute energy savings per disaggregated lighting control strategy for program design use and for reporting to their regulators.

- The project gets at serious system commissioning questions because most lighting control systems estimate end-use device operation (using static lookup tables) both in terms of energy but also light levels—this project addressed that question head-on to develop new algorithms based on dynamic system operation per control strategy to more accurately report these values.

7. **Commercialization (Accomplished and/or Possibilities)**

The reporting methodology developed during this project

8. **Plans for Future Collaboration**

   a) US Industry Collaboration
      a. *Provide a short description on how you've collaborated with US industry and any plans for continued collaboration. Include benefits from this collaboration, unique contributions from the industry partner, etc.*
      b. *List "lessons learned" from working with industry counterparts under the CERC program. ****This will remain confidential if you'd like.***
   b) Chinese Collaboration
      a. *Provide a short description on how you've collaborated with Chinese counterparts and any plans for continued collaboration. Include benefits from this collaboration, unique contributions from the Chinese, etc.*
      b. *List "lessons learned" from working with Chinese counterparts under the CERC program. ****This will remain confidential if you'd like.***

Commissioning & Operational System Optimization

FLEXLAB testing makes it possible to commission the installed lighting controls in stages – something that allows us to isolate the individual control strategies' (daylighting, light level tuning, occupant-responsive lighting) energy saving impacts rather than just measuring the effect of all the strategies together. [**NOTE: this is extremely difficult to achieve in the field because it inflicts too much hardship on the building occupants**.] In a more permissive demonstration environment, it is also possible to explore cost vs. capabilities tradeoffs thus increasing the generalizability of the final project outcomes.

This project gives the Team the opportunity to execute just such an improved experimental design. We also learned that when dealing with private industry as part of the research project, it is necessary to allow significant lead times to obtain equipment and shared resources because, as expected, they are set up to manage a sales/business process rather than a research process. This means that donated or purchased

equipment needs to go through their normal sales channels with appropriate approvals up and down their management chain.

Lutron is looking to collaborate in the future and especially support industry-wide standards setting initiatives as an outgrowth of the research project. They have been a very forthright and supportive partner.

In addition, the lighting controls solutions tested in FLEXLAB were 'driven' by live occupancy data from the CABR building in Beijing. By coordinating the testing between the two sites, the results using real world data will provide outcomes that can be better generalized to a broad swath of commercial floorspace in both China and U.S.

9. Conclusions

While LBNL performed tests on a single lighting system, the testing protocol developed may have wider applicability. We can envision a test procedure for evaluating this broader set of lighting systems that would be similar to the step-dimming test we performed in the FLEXLAB. This test could be done as a power-only "bench top" test that simply compares the measured luminaire power to the lighting control system reported power through a range of different dimming settings. The purpose of this test would be to document errors in energy use, whether they were power-level related (e.g. power reported as 10W but measured as 12W) or time-period related (e.g., power reported to drop after 1 hour but measured to drop after 1 hour, 5 minutes). This test could be used both for lighting control systems that directly measure luminaire power as well as those that report power based on control settings and power look-up tables.

The results from the additional test described above would provide information about lighting controls system-reporting accuracy in general (e.g., are the results found in this report typical of lighting controls system self-reporting or atypical?). This test procedure development may serve as a valuable device for evaluating lighting control system reporting performance, perhaps ultimately resulting in a methodology for certifying self-reporting system accuracy. Codes, standards and/or utility programs could rely on these test procedures to encourage the use of lighting controls systems that are appropriately accurate at self-reporting. This enhanced methodology has significant cost savings and value across industry stakeholder groups in verifying accurately lighting system performance.

One of the key lessons arising from this research that is typically represented as a market gap, is that a significant number of construction projects involving lighting controls system installations lack either the budget, scope description, time frame or singularly accountable professional to adequately obtain and commission accurate luminaire lamp/ballast or LED/driver performance look up tables into a specific manufacturer's control system. Additionally, its important to recognize that frequently, a single project involves integrating a large number of different luminaires from different manufacturers, suppliers, distributors, and wholesale representatives, and that projects lack fully-funded commissioning agents and a single information channel sourcing accurate look up tables. This is not necessarily the failing of the resident lighting controls system reporting, but rather an artifact of the information interjected in it in an inherently 'flawed' construction process. With that said, our research does indicate a modicum of reporting errors associated with varying light source/driver/luminaire combinations. The seriousness of these errors is highly dependent on the extent of employed control strategies and obviously the veracity of the luminaire performance tables. As indicated previously, more research in this area would establish a firmer foundation for the full market impact related to this issue.